PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Dryers

We, HUPP CORPORATION, a corporation of the State of Virginia, United States of America, located at 1135 Ivanhoe Road, Cleveland, Ohio, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates to dryers and, more specifically, to high velocity hood type air dryers for drying continuously moving webs of paper and other materials.

In manufacturing processes such as papermaking and coating, the conventional machines almost invariably run at speeds well below those of which they are capable because the paper or coating cannot be dried at a sufficiently rapid rate. This problem is one of long standing and an extraordinary amount of effort has been devoted to its solution.

At least the following nine methods of hastening the drying process have heretofore been employed, (1) heated cylinder, (2) high velocity hot air, (3) radiant energy, (4) dielectric heating, (5) drying under vacuum, (6) flash dryers, (7) drying by the fluidized bed technique, (8) drying with molten metal, and (9) combinations of two or more of the preceding methods. The first three of these methods and combinations thereof have been found to offer the most promise and large expenditures of time and money have been devoted to their development and improvement.

One highly successful application of the heated cylinder technique is that shown in my Patent No. 1,012,883. Various techniques and apparatus are known for drying paper, coatings, and the like by the application of radiant energy. The present invention constitutes a significant advance in the third of these techniques, high velocity hot air drying. In high velocity hot air dryers, a stream of heated air or air mixed with combustion products is forced through an array of nozzles located adjacent the material to be dried at impinging velocities as high as fifteen thousand feet per minute to remove the moisture from the material. Dryers of this type are effective to increase drying rates substantially when employed in conjunction with heated cylinder dryers.

High velocity hot air dryers employed in the past have been of two general types, those in which the air is heated by diluting or mingling with it hot combustion products (directly heated air dryers) and those in which the air is indirectly heated by steam. There are a number of objections to dryers employing combustion products. First, the requisite combustion products are conventionally generated by one or more gas-fired burners mounted on the paper making, coating, or other machine. These burners pose a rather serious fire hazard. Second, the combustion products contact and may, therefore, contaminate the material being dried. Third, the efficiency of the burners available for this type of dryer is low and their operating cost is therefore high. Fourth, large quantities of fresh air must continuously be introduced into the drying system to support the combustion process. Equal quantities of combustion products and air must be removed from the system, making it virtually impossible to recirculate significant quantities of the moisture laden air and combustion products impinged upon the drying material through the system. Consequently, it is impossible to increase the moisture content of the drying gas by adding to it moisture removed from the drying material. This adversely affects the drying ability of the fluid impinging on the material to be

dried as gases with high humidity can carry more heat than dry gases of the same composition since moisture has about twice the heat capacity of air.

Many of the objections of dryers employing combustion products as the drying gas can be obviated by employing steam heated coils to heat a stream of drying air. This type of dryer (commonly known as the Gardner dryer) however, has another serious drawback which seriously limits its utility—the practical maximum air temperature which can be achieved in such systems is limited to about 300—350°F. Consequently, the differential between the temperature of the air and the material being dried is small and the efficiency of the system is low.

The novel high velocity air dryer provided by the present invention is similar in some respects to the steam heated Gardner dryers heretofore employed. One substantial difference, which provides unexpectedly large increases in operating efficiency, is that, instead of steam, a non-aqueous organic liquid having a boiling point several hundred degrees higher than the boiling point of water is employed to heat the stream of drying air, permitting the drying air to be heated to temperatures on the order of 500—550°F.

As a result of this invention, a number of important advantages are obtained. The fire hazard and contamination problems associated with dryers employing a mixture of air and combustion products as the drying medium is eliminated. Any desired proportion of the spent air can be recirculated through the system to increase the humidity and therefore the heat carrying capacity of the drying air with a consequent increase in the efficiency of the system. In addition, dryers constructed in accordance with the the present invention can readily be provided with a simple, automatic control system for maintaining the humidity of the drying air at the desired level.

Compared with the conventional Gardner dryers, the present invention provides an unexpected and surprisingly higher drying rate and, at the same time, a significant reduction in the power required to circulate the air through the system. Unexpectedly, only a minor increase in the surface temperature of the material being dried is caused by the increase in the temperature of the drying air. Additionally, since the heat transfer medium always remains liquid, the safety hazards posed by superheated steam (which has a pressure of approximately 135 psi at 350°F.) are eliminated.

From the above discussion, it will be apparent that one object of the present invention resides in the provision of improved high velocity air dryers.

Another object of the present invention resides in the provision of novel high velocity air dryers providing drying air uncontaminated by combustion products heated to temperatures heretofore achievable only in dryers employing heated combustion products as the circulating medium.

In conjunction with the preceding object, another object of the present invention resides in the provision of novel, high velocity air dryers which eliminate the fire hazard and contamination problems associated with dryers utilizing combustion products as the circulating medium and which have efficiencies substantially higher than dryers of the latter type.

Yet another object of the present invention resides in the provision of novel high velocity air dryers capable of operating at substantially higher temperatures and with substantially greater efficiencies than conventional steam heated Gardner type dryers.

In conjunction with the preceding object, it is a further object of the present invention to provide novel high velocity air dryers in which the heat transfer medium circulated through the air heating unit is always in the liquid state, eliminating the problems involved in handling superheated steam.

Another object of the present invention resides in the provision of novel high velocity air dryers in accordance with the preceding objects and having control systems for automatically regulating the humidity of the drying air.

Other objects and further novel features of the present invention will become more fully apparent from the appended claims and as the ensuing detailed description and discussion proceeds in conjunction with the accompanying drawing, in which:

Figure 1 is a partially diagrammatic perspective view of a high velocity air drying system constructed in accordance with the present invention;

Figure 2 is a section through a hood employed in the system of Figure 1 and is taken substantially along line 2—2 of that figure;

Figure 3 is a view similar to Figure 2, but taken substantially along line 3—3 of Figure 1;

Figure 4 is a fragmentary view of the hood, to an enlarged scale, showing in more detail the array of nozzles employed to direct the heated, circulating drying air onto the material to be dried;

Figure 5 is a graphic chart illustrating the comparative performance characteristics of high velocity air dryers of the Gardner type and an embodiment of the improved dryer of the present invention;

Figure 6 is a graphical illustration of the relation between dewpoint and specific humidity;

Figure 7 is a schematic illustration of a control system which may be employed to

automatically regulate the humidity of the drying air;

Figure 8 is a section through the control system sensing unit taken substantially along line 8—8 of Figure 9; and

Figure 9 is a section through the sensing unit taken substantially along line 9—9 of Figure 8.

In the drying of paper, coatings, and similar liquid bearing materials on heated drums, the heat applied to the material by the drum causes molecules of the liquid to evaporate from the surface of the material, forming a dry boundary layer in the material and a vaporous barrier layer adjacent the surface of the material. As the drying process continues, molecules of the liquid in the material migrate from the material through the dry boundary layer and escape from the material into the barrier layer of vapor adjacent its surface. As the concentration of molecules in the barrier layer increases, these molecules diffuse toward areas of lower concentration. Since the dry boundary layer of the material is immediately adjacent the paper barrier layer, a portion of the diffusing molecules will return to the material, retarding the drying process.

To remove the liquid from the barrier layer and hasten the drying process, high velocity air type dryers have been developed. These dryers direct and impinge heated jets of air at high velocity against the surface of the material to be dried, dislodging the molecules of vapor from the barrier layer and increasing their kinetic energy which causes them to pass into the spent drying air as it is exhausted from the drier. In addition, the heated air impact transmits a considerable amount of heat to the material, increasing the rate at which the molecules of liquid migrate through and evaporate from the surface of the material being dried.

Referring now to the drawing, Figure 1 illustrates a high velocity air type dryer 10 designed to hasten the drying of paper, coatings, and similar material through the heat transfer mechanism described above. Dryer 10 includes a closed air heating system 12 comprising a heating unit 14 for heating a non-aqueous liquid heat transfer medium, an air heating unit 16, and a pump 18 for circulating the heat transfer medium between units 14 and 16. A stream of air is forced by blower 20 through heating unit 16, where it is heated to the desired temperature, preferably 500—550°F., and through a supply duct 22 to an air cap or hood 24 from which the heated air is directed at high velocity against the surface of a web of material 26 moving in the direction of the arrows over a heated cylinder 28 such as that shown in U.S. Patent No. 3,237,314, referred to above, and a guide roller 30. The velocity of the air impinging upon the material to be dried may range from 6000—12000 fpm and is preferably on the order of 6000 fpm. After it impinges on web 26 the spent air is exhausted from air cap 24 through a return duct 32 by blower 20 which recirculates the spent air to air heating unit 16.

Air heating system 12 is of the same general construction as the heating system disclosed in copending application No. 45,256/63 Ser. No. 1031438, filed November 15, 1963, for HIGH TEMPERATURE HEATING APPARATUS. The heating unit 14 of this system, which is of substantially conventional construction, includes continuous, finned heating tubes 34 (only one of which is shown) through which the circulating liquid medium flows and over which hot combustion gases generated by combustion units 36 pass. Heating tubes 34 and one or more combustion units 36 are housed in an outer shell 38 which may be lined with an appropriate refractory (not shown) to radiate heat to heating tubes 34 and which has a stack 40 through which the combustion gases may be exhausted after they have traversed heating tubes 34. The combustion units 36 may be gas or oil burners or solid fuel burners if desired.

Fuel flows to combustion units 36 through an inlet line 42 in which an automatically controlled valve 44 (such as a Minneapolis Honeywell Series 800 valve) is interposed. Valve 44 is preferably controlled by a conventional temperature controller 46 responsive to the temperature of the circulating medium discharging from the heating tubes 34 in heating unit 14 to insure that the circulating medium is invariably discharged from the heating unit at the same temperature. Temperature controller 46 may be any desired, commercially available unit such as the recording type Minneapolis Honeywell ELECTRONIK controller, or the Minneapolis Honeywell non-recording model T456B controller.

The outlets of heating tubes 34 are connected to a supply conduit 48 through which the heated circulating liquid medium is forced by pump 18 to one or more finned heating tubes 50 in air heating unit 16 which includes, in addition to heating tubes 50, a plenum chamber 52 disposed around the tubes. From heat exchanger tubes 50, the circulating heat transfer medium is pumped back to heating unit 14 through a return conduit 54.

To insure proper operation of dryer 10, the heated air passing from air heating unit 16 into supply duct 22 must be maintained at a uniform temperature. To this end, a bypass conduit 56 is connected between supply conduit 48 and return conduit 54 in parallel with the heat exchange tubes 50 in air heating unit 16. Interposed in bypass conduit 56 is a three-way valve 58 such as the Minneapolis Honeywell 800 Series valve which is controlled by a temperature controller 60 responsive to the temperature of the heated air flowing

from plenum 52 of air heating unit 16 into air supply duct 22. Temperature controller 60 may, if desired, be of the same type as temperature controller 46. Temperature controller 60, which has a sensing element 62 disposed in air supply duct 22 adjacent its inlet end, proportions the flow of heated circulating liquid medium between the heat exchange tubes 50 in air heating unit 16 and bypass conduit 56 to maintain the temperature of the air flow into the supply duct at the temperature for which the controller 60 is set. In general, as the air temperature drops, an increasing portion of the circulating liquid is diverted to the air heating unit; conversely, as the air temperature rises, an increasing proportion of the heated circulating liquid will be diverted through bypass conduit 56.

One of the novel features of the present invention resides in employing a high boiling point hydrocarbon liquid as the circulating medium, permitting it to be circulated at extremely high temperatures in liquid form. Consequently, the air delivered to air hood 24 may be heated to substantially higher temperatures than has heretofore been possible, substantially increasing the efficiency of dryer 10. At the same time, as the heat transfer medium always remains in liquid form, the heating system components through which the circulating medium flows need be designed to withstand only very low pressures. For the high velocity air dryers disclosed in the present application, the preferred heat transfer liquid is Aroclor 1248, a chlorinated biphenyl produced by Monsanto Chemical Company. Aroclor 1248 liquid may be heated to temperatures on the order of 550—570°F. without boiling and without exceeding a permissive rate of decomposition. At that temperature Aroclor 1248 has a decomposition rate of less than 0.001% per hour of system operation.

As explained in copending application 45,256/63, Ser. No. 1031438, referred to above, when a liquid such as Aroclor 1248 is employed as a heat transfer medium a reasonably constant, high velocity flow, preferably on the order of about 8 feet per second, must be maintained in the heating system since, if constant circulation is not maintained, the circulating medium in the heating tubes 34 of heating unit 14 will be overheated and will polymerize, forming a thick sludge which will adversely affect the heat transfer efficiency of the system. To prevent a flow stoppage in conduits 48 or 54 or in heating tubes 50 from having this adverse effect, a bypass conduit 64 is connected between main supply conduit 48 adjacent the discharge ends of heating unit tubes 34 and main return conduit 54 on the inlet side of pump 18. Flow through bypass conduit 64 is controlled by a bypass valve 66 (such as a Minneapolis Honeywell Series 800 valve) which, in turn, is regulated by a differential pressure controller 68, the two bellows type sensing elements of which (not shown) are located, respectively, on the inlet and discharge sides of circulating pump 18. The sensing elements are connected by leads 70 and 72 to a pressure transducer 74 which, in turn, is connected by a lead 76 to differential pressure controller 68. Differential pressure controller 68 may be of any conventional construction such as the Differential Pressuretrol manufactured by the Minneapolis Honeywell Regulator Company.

Should a condition arise tending to decrease the flow through heating system 12, as by an obstruction in conduits 48 or 54 or in heating tubes 50, the pressure differential between the inlet and outlet sides of pump 18 will increase causing differential pressure controller 68 to open bypass valve 66, allowing the circulating medium to flow from supply conduit 48 through bypass conduits 64 into return conduit 54. As a result, the flow of liquid through heating unit 14 is maintained constant, thereby preventing the circulating medium from over heating.

When the flow of fluid through the supply and return conduits and heating tubes 50 again increases, the differential between the pump suction and discharge pressures will decrease. Differential pressure controller 68 will then close bypass valve 66, decreasing the flow of liquid through bypass conduit 64 and increasing the flow through main supply conduit 48.

Heating system 12 is described in greater detail in copending application 45,256/63, referred to above, to which reference may be had if deemed necessary for a more complete understanding of the present invention. Since this system is described in the copending application and since, it, by itself, is not part of the present invention, it is not seen that a more elaborate description of the system is required herein.

As was described above, a stream of air is forced through plenum chamber 52 of air heating unit 16 and over heat exchange tubes 50 by blower 20, heating the air to a temperature preferably on the order of 550°F. From plenum chamber 52, the heated air is forced by blower 20 through air supply duct 22 into a transition duct section 78 connected to the outlet end 80 of duct 22. Transition section 78 extends through the top wall 81 of air cap 24 into fluid communication with the interior of a plenum chamber 82 overlying and in fluid communication with the inlets of nozzles 84 in air cap 24.

Referring now to Figures 2—4, nozzles 84 are disposed in parallel, side-by-side relationship and extend across the entire width of the web of material 26 and about half way around heated cylinder 28. Each of the nozzles 84 is formed from two identical sheet metal

nozzle members 88 disposed in mirror image relationship. Members 88 have parallel sides 90 and converging nozzle portions 92 which cooperate to form, in each nozzle, a narrow elongated nozzle outlet slot 94 adjacent the surface of the web of material 26. The two nozzle members 88 of each nozzle are joined by a top wall member 96 which closes the end of the nozzle opposite outlet slot 94 as by welding or brazing. Nozzles 84 are connected by sheet metal ribs 98 which extend between and are welded or brazed to the juxtaposed nozzle members 88 of adjacent nozzles 84 at the intersection of their wall portions 90 and nozzle portions 92. Nozzles 84 are supported with their outlets 94 closely adjacent the web of material 26 by the side walls 100 and 102 of air hood 24 to which the ends of nozzle members 88 may be secured as by welding or brazing. Cover plates 103 bolted or otherwise fixed to side walls 100 and 102 (which are connected by a side wall 104) close the open ends of the nozzles.

As is best shown in Figures 1 and 4, plenum chamber 82 has a crescent-like configuration provided by end walls 105 and 106 between which a top wall 108 extends. The lower edges 110 of plenum chamber side walls 105 and 106 are fixed to the top walls 96 of nozzles 84 to provide an air tight seal between the nozzles and the plenum chamber. As is shown in Figure 4, the top walls 96 of nozzles 84 are cut away between the end walls 105 and 106 of plenum chamber 82, providing apertures 112 (see Figure 4) through which the heated drying air may flow from plenum chamber 82 into the interiors of nozzles 84 as indicated by the arrows in Figure 2. As is shown in Figures 2 and 4, the gaps between adjacent nozzles 84 beneath plenum chamber 82 are spanned by metal plates 114 which prevent the heated air from flowing out of the plenum chamber between adjacent nozzles.

After the heated drying air impinges on the surface of the web of material 26 being dried, it flows upwardly (see Figures 3 and 4) through elongated slots 116 formed in the ribs joining nozzles 84, carrying with it a burden of vapor removed from the barrier layer adjacent the surface of web 26. Referring again to Figure 1, the spent air and its burden of moisture is drawn by blower 20 through a transition section 118 of air hood 24 into air return duct 32 through which it is recirculated to the plenum chamber 52 of air heating unit 16. By recirculating the moisture laden air through the air heating unit, the moisture content of the drying air delivered to air cap 24 is increased—preferably to a specific humidity in the range of 0.4 to 2.0 pounds of water per pound of dry air—thereby adding to the heat carrying capacity of the drying air. The preferred value of specific humidity is on the order of 1.0 pound of water per pound of dry air although it is contemplated that this value will be varied within the limits indicated above for different applications of the present invention.

To control the moisture content of the air delivered to air cap 24, a make-up air duct 120 and a vent air duct 122 are provided. As is shown in Figure 1, make-up air duct 120 communicates with return duct 32 on the inlet side of blower 20. Vent air duct 122 communicates with a duct 124 connected between the outlet of blower 20 and the inlet to the plenum chamber 52 of air heating unit 16. Valves 126 and 128, disposed in make-up air duct 120 and vent air duct 122, respectively, may be adjusted to discharge selectively variable proportions of the moisture laden spent air returned from air hood 24 and replace it with fresh air of lower humidity to maintain the specific humidity of the air delivered to air cap 24 at the desired level.

Figure 7 illustrates schematically an automatic control system 130 for maintaining constant the humidity of the heated air discharged through the nozzles 84 in air cap 24. Automatic humidity control system 130 includes a sensing unit 132, an amplifier-controller 134, and a power actuator 136. Sensing unit 132, which is located in return duct 32, generates a signal indicative of the specific humidity of the air flowing through the return duct which it transmits to amplifier-controller 134 (which may be, for example, a Model GP107 manufactured by General Electric Co.). Amplifier-controlled 134 amplifies the signal and transmits it to power actuator 136 which may by a conventional low speed, reversible D.C. motor. Power actuator 136 is operatively connected to and adjusts the valves 126 and 128 in make-up air duct 120 and vent air duct 122, respectively, to continuously vary the proportions of recirculated and fresh air to maintain the humidity of the air impinging upon the web of material 26 moving through the dryer constant.

Referring now to Figure 6, sensing unit 132 takes advantage of the well known physical facts that (1) as the specific humidity of a body of air increases, its dewpoint also increases; and (2) that if a body of air contacts a surface having a temperature lower than the dewpoint of the air, the moisture in the air will condense on the cooler surface. Thus, with reference to Figure 6, if the specific humidity of a body of air is 0.4 pounds of water per pound of dry air, the dewpoint of the air is 168°F., and the moisture in that body will condense on any surface having a temperature lower than 168°F. Similarly, if the specific humidity of the air is 0.3 pounds of water per pound of dry air, the dewpoint of that air is 160°F., and moisture will condense out of the air onto a surface having a temperature lower than 160°F.

Referring next to Figures 8 and 9, sensing

unit 132 includes a copper plate 138 mounted in return air duct 32 and having a highly polished, chrome plated surface 139 facing the interior of the duct. Plate 138 is maintained at a constant temperature as by circulating water or other constant temperature liquid through a chamber 140 into heat transfer relationship with the rear or outer side of plate 138. Chamber 140 is provided with an inlet line 142 and an outlet line 144 and is surrounded by insulation indicated generally by reference character 145. The insulation is retained in place by a casing 146 attached to duct 32 in any desired manner. A thermocouple 147 may be mounted in contact with the outer side of plate 138 to provide a continuous indication of its temperature. The liquid circulated through chamber 140 may be heated in any desired manner as, for example, that shown in United States Patent No. 1,960,658 issued ay 29, 1934, to K. P. Brace for "Dew Point Control Device".

The temperature of plate 138 is selected so that, if the specific humidity of the air flowing through return duct 32 is above the desired level, the dewpoint of the flowing air will rise above the temperature at which plate 138 is maintained and the moisture in the flowing air will condense on and fog the highly polished chrome plate surface of plate 138. For example, if it is desired to maintain the specific humidity of the air flowing through return duct 32 at 0.3 pounds of water per pounds of dry air, plate 138 will be maintained at a temperature of 160°F. If the specific humidity of the air flowing through the return duct rises above 0.3 pounds of water per pound of dry air, the dewpoint of the air will rise above 160°F. and the moisture in the air will condense out on the polished surface of plate 138.

With continued reference to Figures 8 and 9, the presence of fog or condensate on plate 138 is detected by reflecting a beam of light emanating from lamp 148 from the chrome plated surface of plate 138 into a photoelectric cell 150. Thus, if the specific humidity of the air flowing through duct 32 rises above the desired level, condensate will form on the surface of plate 138 and the intensity of the light reaching photoelectric cell 150 will be substantially less than when no condensate is present. Therefore, the intensity of the current generated by photoelectric cell 150 is diminished, producing a signal which, as explained above, is amplified and transmitted to power actuator 136. In the above circumstances, power actuator 136 opens valve 128 in vent duct 122 and valve 126 in make-up air duct 120 to replace part of the moisture laden recirculated air with fresher, drier, make-up air. Lamp 148 and photoelectric cell 150 are mounted in appropriate housings 152 and 153 attached in any desired manner to duct 32.

In the preferred embodiment illustrated in Figures 8 and 9, the fog forming and detecting system including plate 138, the apparatus provided for keeping plate 138 at a constant temperature, lamp 148, and photoelectric cell 150, is duplicated, with the components of the second system being indicated by reference characters identical to those employed in conjunction with the first, but primed.

The two systems operate in the same manner except that, assuming that is desired to maintain the specific humidity of the air flowing through return duct 32 at 0.3 pounds of water per pound of dry air, plate 138 will be maintained, for example, at a temperature of 159°F., and plate 138′ at a temperature of 161°F. In this case, if the specific humidity of the air flowing through duct 32 falls more than slightly below 0.3 pounds of water per pound of dry air, the polished surfaces of both plates 138 and 138′ will be unfogged or clear. If the specific humidity of the air is or is close to 0.3 pounds of water per pound of dry air, the polished surface of plate 138 will be fogged, but the surface of plate 138′ will be unfogged. If the specific humidity of the air increases to more than slightly above 0.3 pounds of water per pound of dry air, the surfaces of both plates 138 and plate 138′ will be fogged. By combining the output voltages of the two photoelectric cells 150 and 150′, a continuous variable signal can be generated which will detect minute increases and decreases in the specific humidity of the air flowing through duct 32. Thus, by employing a dual system, the specific humidity of the air can be maintained at the desired level within very close tolerances.

Figure 5 illustrates graphically the advantages achieved by the present invention in comparison with the conventional steam heated Gardner type dryer. The present invention, as discussed above, makes it possible to deliver the drying air to the material to be dried at a temperature on the order of 550°F. as compared to a maximum air temperature of about 350°F. in the Gardner type dryer. As a result, as shown by the curve "Combined Drying Rate", the drying rate may be increased from approximately 11 pounds of moisture removed per hour per square foot of material to 18 pounds per hour per square foot of material, an increase of more than 50%.

Second, it has been discovered that drying capacity is a function of both air temperature and velocity. If the temperature is increased, the velocity may be decreased. Therefore, high air temperature permits high drying rates at relatively low air velocity with a corresponding reduction in the power required to drive the air circulating blower. By heating the air to 550°F. as opposed to 250°F., the horsepower of the motor employed to drive blower 20 may be reduced from about

0.48 horsepower per square foot of dryer surface to about 0.42 horsepower per square foot of dryer surface, a savings of approximately 12.5% (see the curve "Main Fan Hp/Ft). Further, by heating the drying air to 550°F., the optimum pressure of the steam by which cylinder 28 is heated may be reduced to 4 psig as compared with an optimum pressure of nearly 10 psig if the air is heated to 350°F., the maximum temperature obtainable in the steam heated Gardner type dryer. As is shown by the curve "Sheet Surface Temperature", this significant increase in drying rate and substantial decrease in fan horsepower and optimum steam cylinder pressure are accomplished with only about a 10°F. rise in the surface temperature of the material being dried. Therefore, even though the drying air is heated to a substantially higher temperature than has heretofore been possible, the material being dried will be not be overheated.

Another advantage of the present invention is that the pressure of the circulating medium in the tubes 50 of air heating unit 16 and in the other components of heating system 12 through which the medium circulates is substantially atmospheric. In a Gardner dryer at 350°F., the pressure of the steam circulated through the air heating unit is approximately 170 psig. The reduction in pressure provided by the present invention makes it possible to effect substantial savings in the cost of the dryer and eliminates the hazard present in handling steam at high temperature and pressures.

WHAT WE CLAIM IS:—

1. A high velocity hood type air dryer for removing moisture from continuously moving webs of material, comprising means for heating a stream of air to a temperature of not less than 500°F: means for delivering the air to and forcing it at a velocity of not less than 6,000 feet per minute against the surface of a web of material to be dried to evaporate the moisture therefrom: and means for recirculating at least part of the cooled, moisture laden drying air from adjacent said web to said heating means to maintain the specific humidity of said air at not less than 0.4 pounds of water per pound of dry air.

2. The dryer as claimed in claim 1, wherein said heating means comprises an air heating chamber; means for forcing air through said chamber; and a tube type heat exchanger in said chamber.

3. The dryer as claimed in claim 2, wherein said heating means further comprises a heating unit including a tube type heat exchanger; means connecting the heat exchangers in said air heating chamber and in said heating unit into a closed circulation system; and a liquid having a boiling point of not less than 500°F in said closed system.

4. The dryer as claimed in any of the preceding claims, wherein said air delivering means comprises a plurality of elongated nozzles adapted to be disposed in substantially parallel, side-by-side relationship adjacent the web of material to be dried; means providing elongated fluid discharging slits in the sides of said nozzles adjacent said web; a plenum chamber extending over said nozzles; means establishing fluid communication between said plenum chamber and the interiors of said nozzles; and duct means establishing fluid communication between said air heating means and said plenum chamber.

5. The dryer as claimed in claim 4, including a hood surrounding said nozzles and said plenum chamber; and exhaust duct establishing fluid communication between said hood and said air heating means: and means providing a make-up air vent in said duct.

6. The dryer as claimed in claim 4, including ribs extending substantially the length of and interconnecting adjacent ones of said nozzles; and means providing openings in said ribs to permit air to pass from adjacent said web through said ribs into said exhaust duct.

7. The dryer as claimed in any of the preceding claims, together with means for maintaining the specific humidity of said air substantially constant.

8. The dryer as claimed in claim 7, wherein said recirculating means includes a recirculating air duct and the means for maintaining said specific humidity constant includes a member having a highly polished surface in communication with the interior of said recirculating air duct; means for maintaining said member at a temperature equal to the dewpoint of air having a specific humidity which, at the temperature at which said air is circulated, will cause said air to be at the desired humidity; and means for detecting the presence of condensate on said highly polished surface.

9. The dryer as claimed in claim 8, wherein the means for maintaining said humidity constant further includes means operatively connected to said detection means for generating a signal if condensate forms upon said highly polished surface; means for amplifying said signal; and means including power actuator means responsive to said amplified signal for introducing fresh air of lower humidity into said recirculated air to lower the humidity thereof.

10. A high velocity air dryer for removing moisture from continuously moving webs of material, comprising; a hot air heater comprising an air heating chamber and a tube type heat exchanger in said chamber; a duct for conducting hot air from said chamber to the material to be dried; a heating unit including a tube heat exchanger; supply and return conduits establishing fluid communica-

tion between said heat exchangers and together with said heat exchangers constituting a circulation system; a liquid having a boiling point of not less than 500°F in said system; means for effecting circulation of said liquid at a substantially constant rate through said system; a bypass conduit establishing fluid communication between said supply and return conduits and connected in parallel with the heat exchanger in said air heater; and means responsive to the temperature of the air in said hot air duct for proportioning the flow of said liquid between said bypass conduit and the air heater exchanger to maintain in the air flowing duct at a substantially uniform temperature.

11. The dryer as claimed in claim 10, including a circulation maintaining bypass conduit establishing fluid communication between said supply and return conduits and connected to said supply and return conduits closely adjacent the inlet of the heating unit heat exchanger and the intake of the liquid circulating means, respectively; and means responsive to the pressure differential between the inlet and outlet sides of said liquid circulating means for diverting flow through the circulation maintaining bypass in proportion to decrease in flow through the circulation system to maintain a substantially constant flow of liquid through the heat exchanger in said heating unit and thereby prevent overheating of the circulating liquid.

12. The dryer as claimed in claims 10 or 11, wherein the liquid in said system is a chlorinated biphenyl having a boiling point of not less than 500°F and a decomposition rate at that temperature of not greater than 0.001% per hour of system operation.

13. The method of drying a continuously moving web of material, comprising the steps of heating a stream of air in an environment which is free of combustion products to a temperature of not less than 500°F to provide heated air which has a temperature of at least 500°F and is free of combustion products; directing the heated air at high velocity against the surface of the material to be dried; and recirculating and reheating the air impinged upon said web to increase the moisture content and thereby the drying capabilities of the air directed against the web of material to be dried.

14. The method as claimed in claim 13, wherein the air is indirectly heated.

15. The method as claimed in either of the preceding claims 13 or 14, wherein said air is directed against the material to be dried at a velocity of not less than 6,000 feet per minute.

16. A high velocity hood type air dryer substantially as hereinbefore described with reference to the accompanying drawings.

17. A method of drying a continuously moving web of material, substantially as hereinbefore described.

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Fig. 1

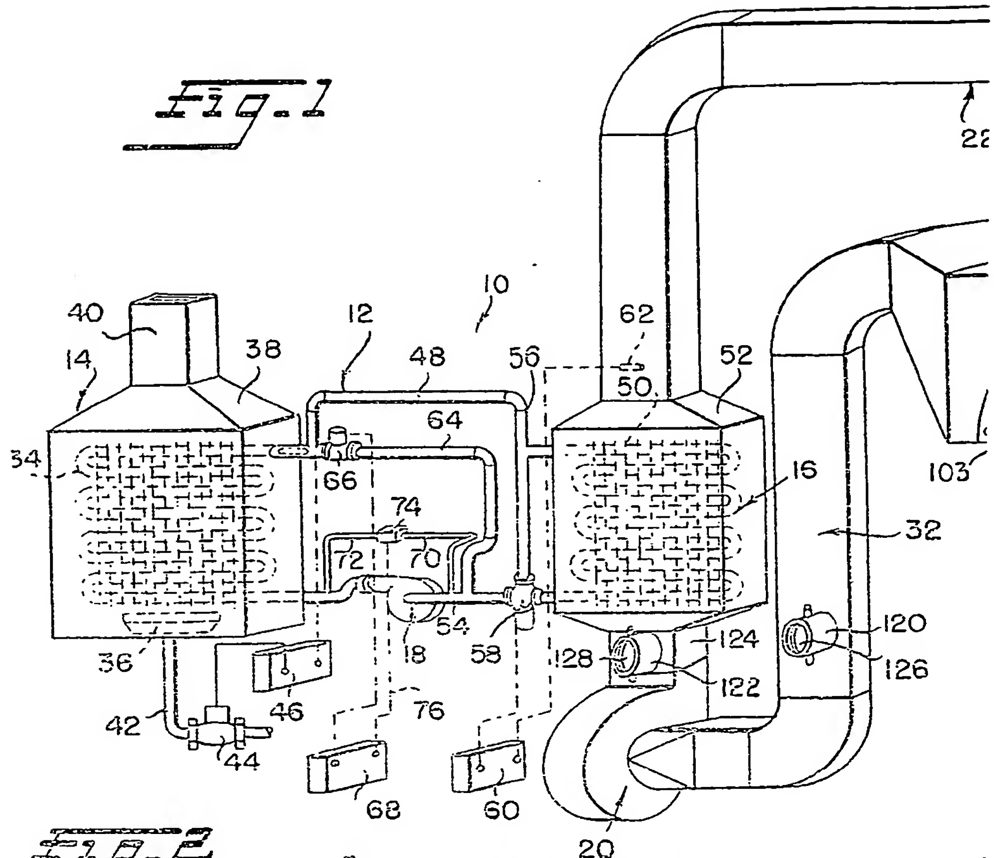
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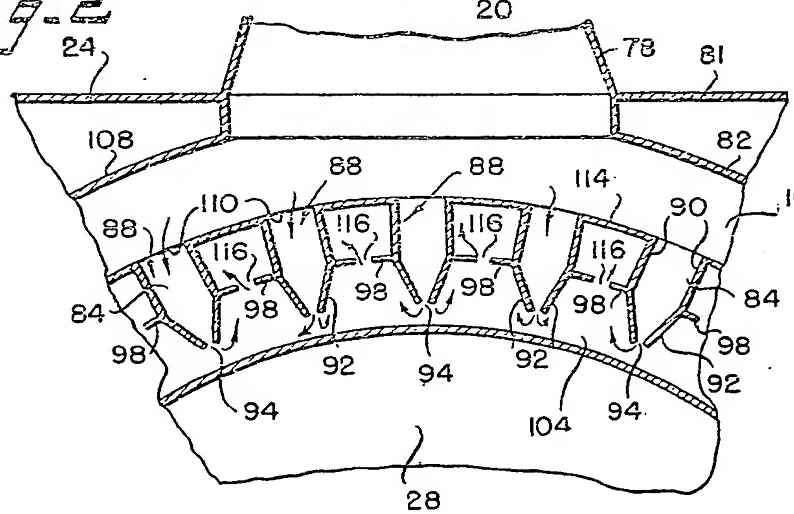
Fig. 2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1046087 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

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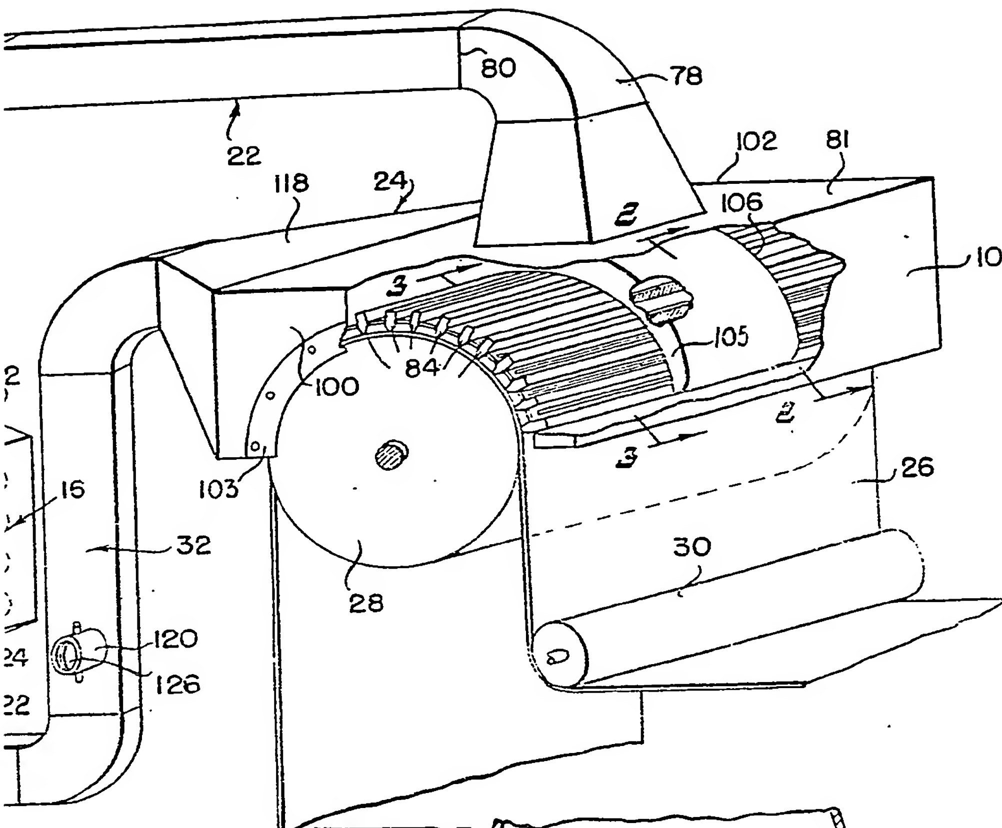
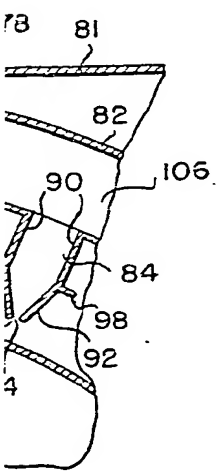


FIG. 3



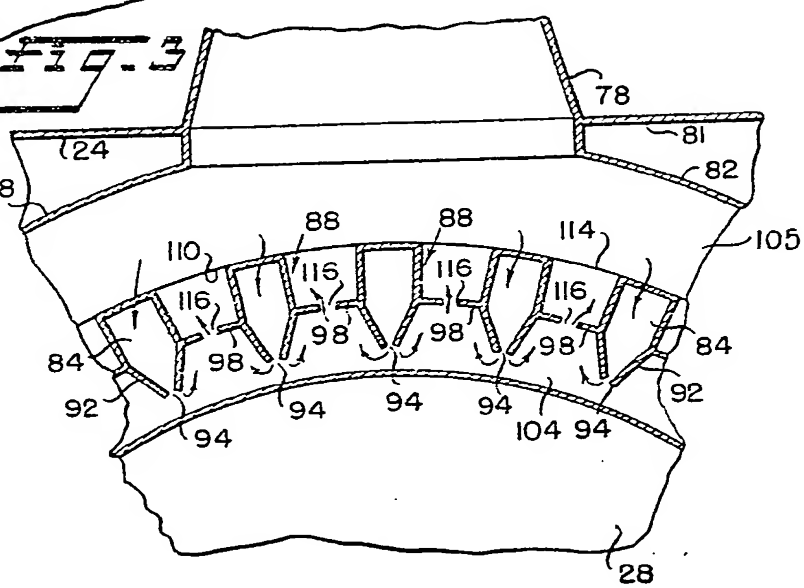


Fig. 1

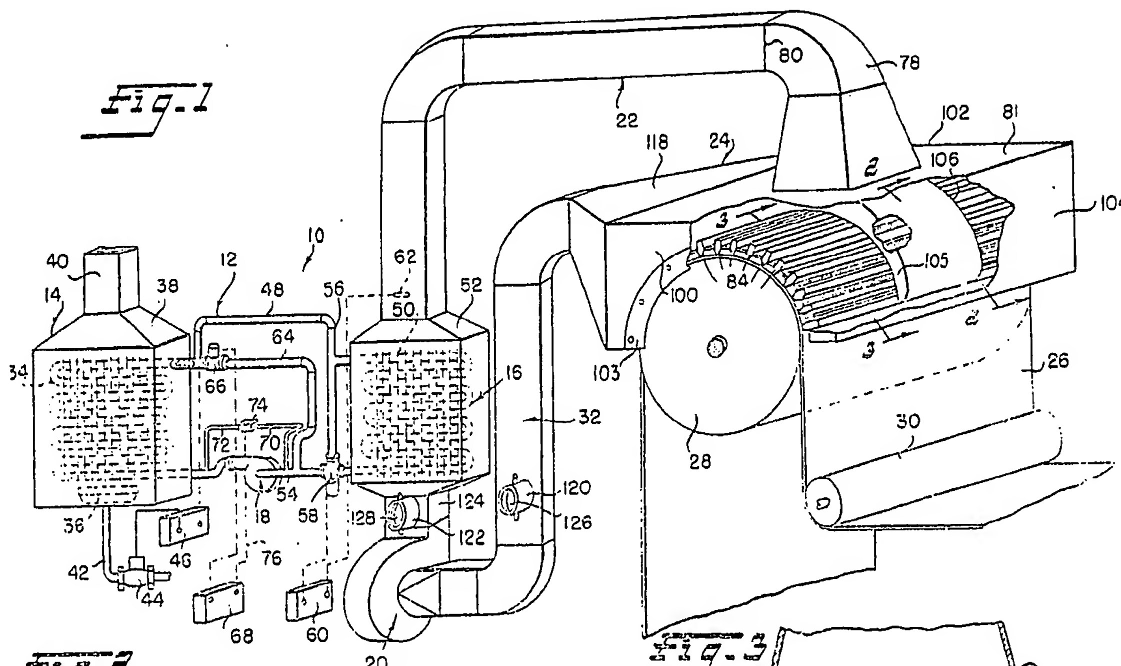
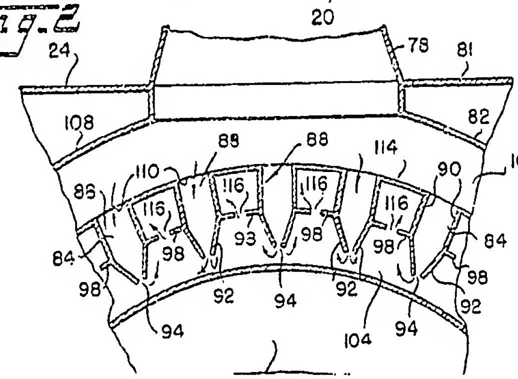


Fig. 2



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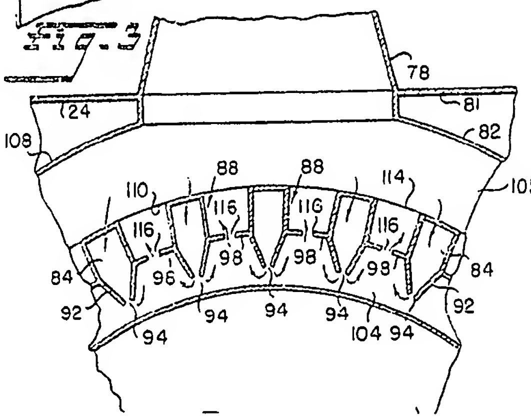

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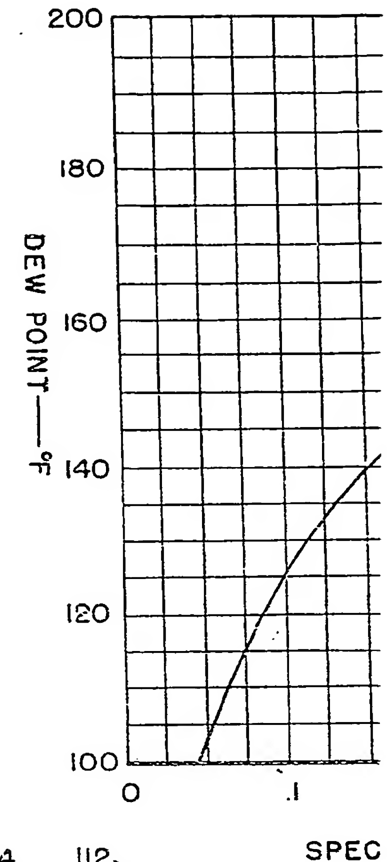
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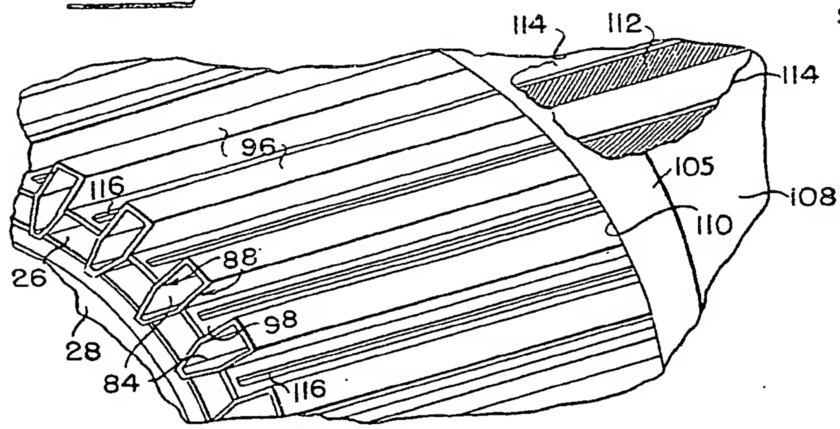
180
160
140
120
100
DEW POINT —°F
0
.1
SPEC

Fig. 4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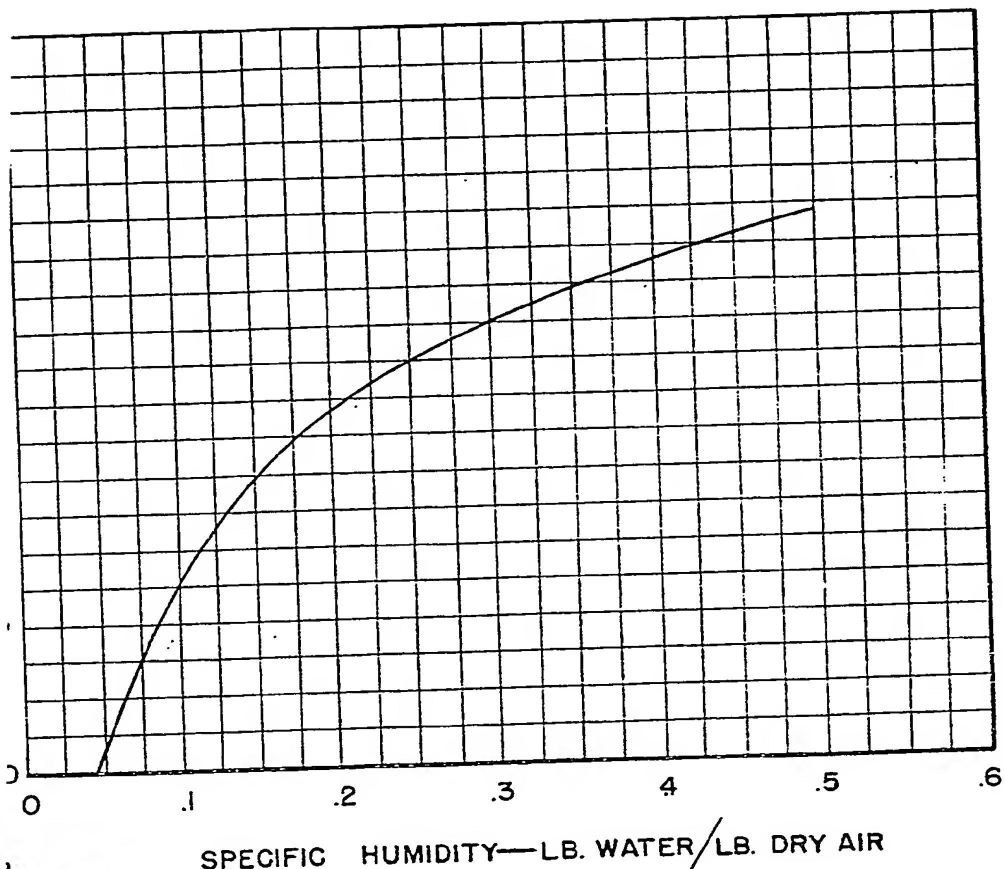
1046087 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2



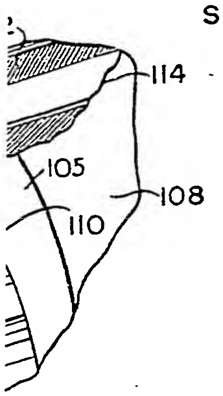
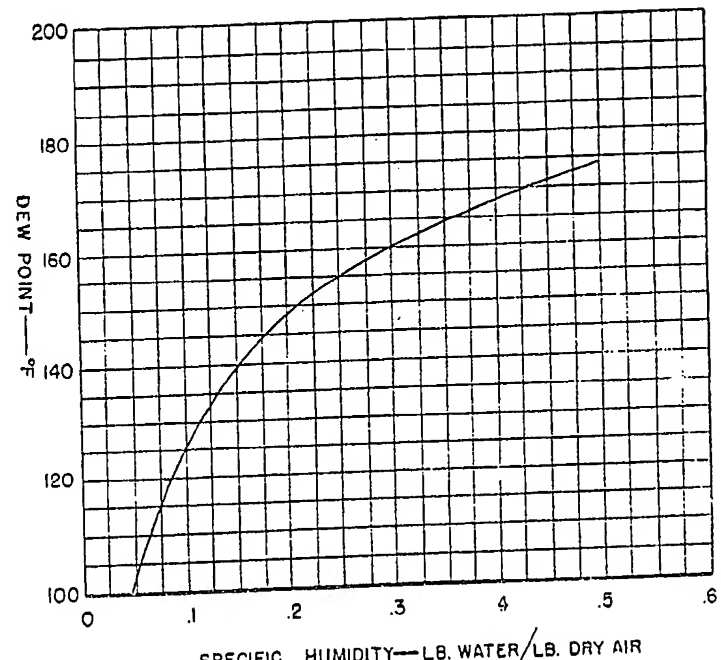


Fig. 6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180
160
140
120
100
DEW POINT—°F
0
.1
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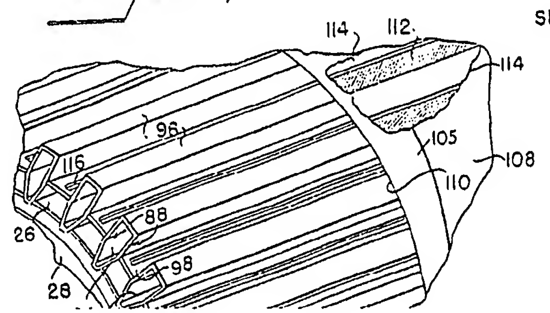
.3
4
.5
.6
SPECIFIC HUMIDITY—LB. WATER/LB. DRY AIR

Fig. 4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114
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116
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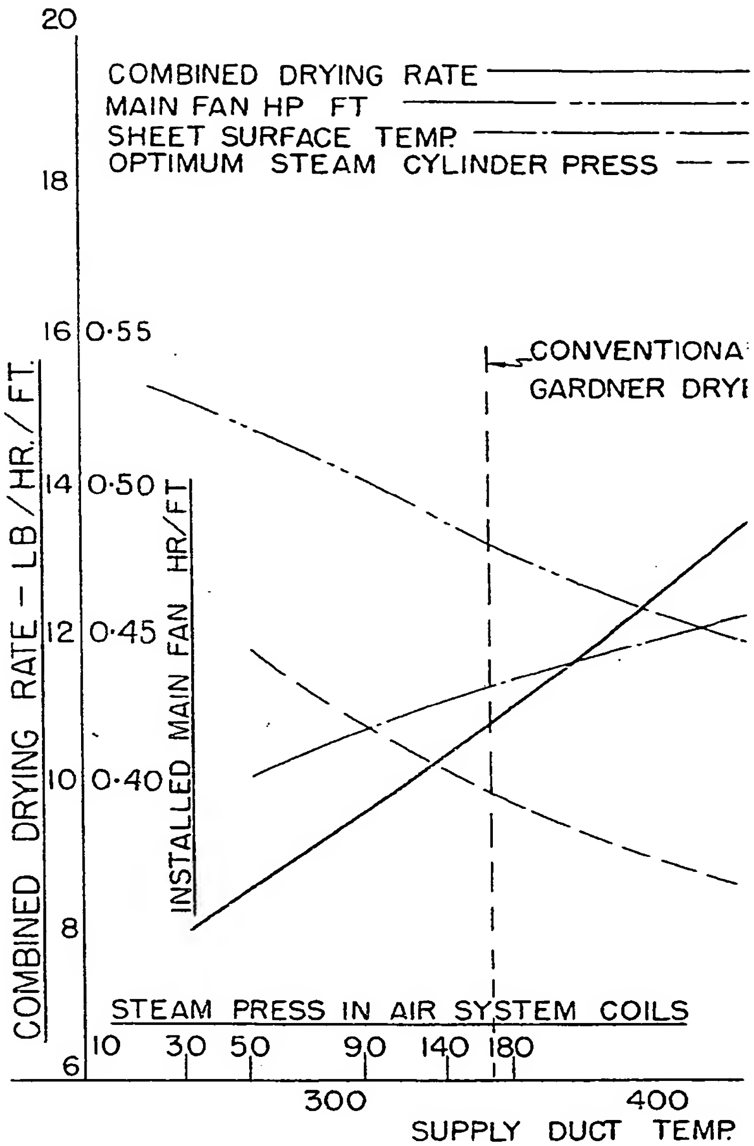
108
110
88
26
98
28

Fig. 5


COMBINED DRYING RATE
MAIN FAN HP FT
SHEET SURFACE TEMP.
OPTIMUM STEAM CYLINDER PRESS
CONVENTIONA
GARDNER DRY
COMBINED DRYING RATE – LB./HR./FT.
INSTALLED MAIN FAN HR/FT
20
18
16
14
12
10
8
6
0·55
0·50
0·45
0·40
STEAM PRESS IN AIR SYSTEM COILS
10 30 50 90 140 180
300
400
SUPPLY DUCT TEMP.

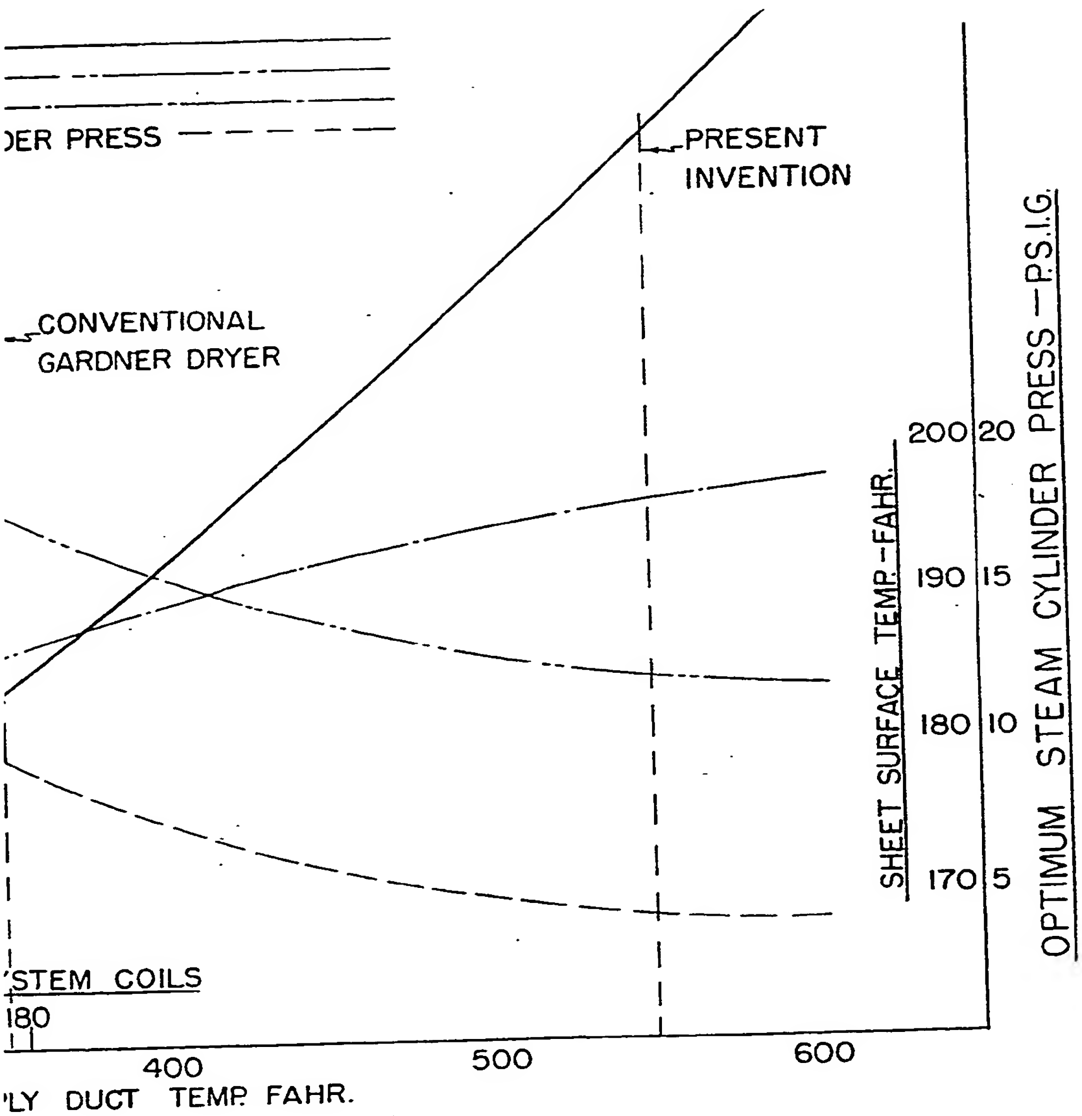
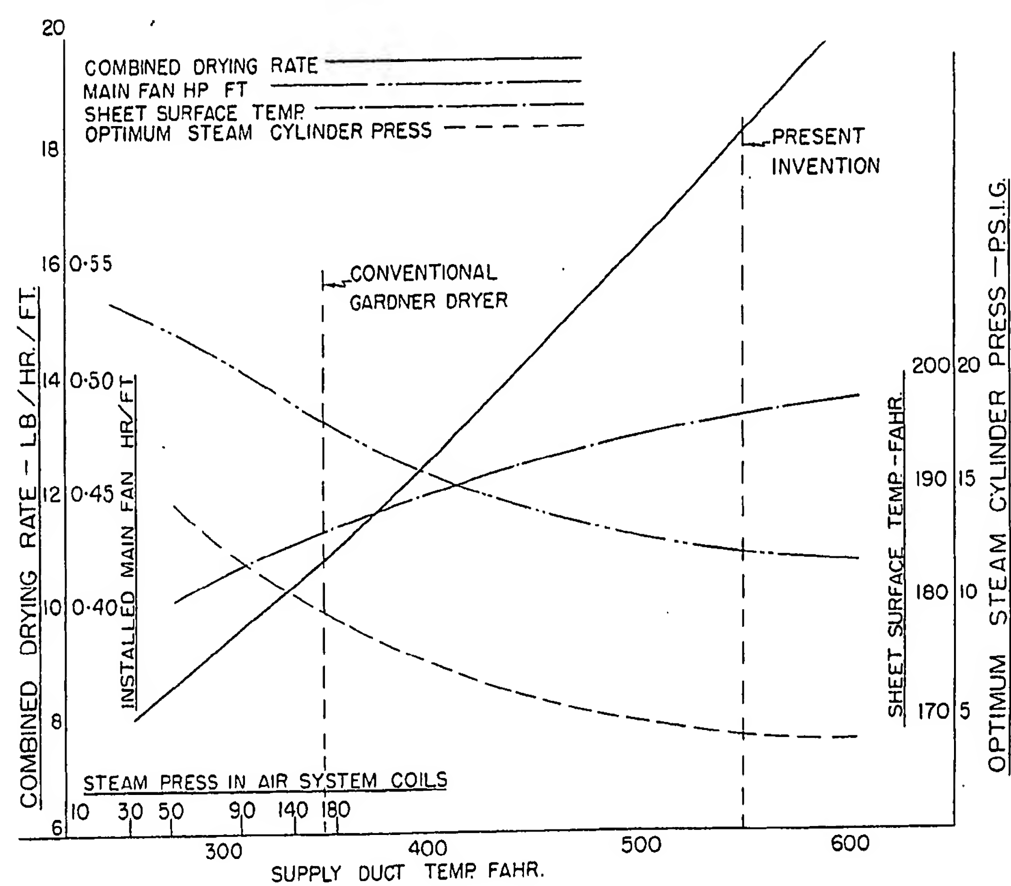

ER PRESS
PRESENT INVENTION
CONVENTIONAL GARDNER DRYER
STEM COILS
180
400
500
600
LY DUCT TEMP. FAHR.
200
190
180
170
20
15
10
5
SHEET SURFACE TEMP.-FAHR.
OPTIMUM STEAM CYLINDER PRESS.—P.S.I.G.

Fig. 5


COMBINED DRYING RATE
MAIN FAN HP FT
SHEET SURFACE TEMP
OPTIMUM STEAM CYLINDER PRESS
PRESENT INVENTION
CONVENTIONAL GARDNER DRYER
COMBINED DRYING RATE - LB/HR./FT.
INSTALLED MAIN FAN HR/FT
SHEET SURFACE TEMP-FAHR.
OPTIMUM STEAM CYLINDER PRESS - P.S.I.G.
STEAM PRESS IN AIR SYSTEM COILS
SUPPLY DUCT TEMP FAHR.
20
18
16
14
12
10
8
6
0·55
0·50
0·45
0·40
200
190
180
170
20
15
10
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10
30
50
90
140
180
300
400
500
600

Fig. 7

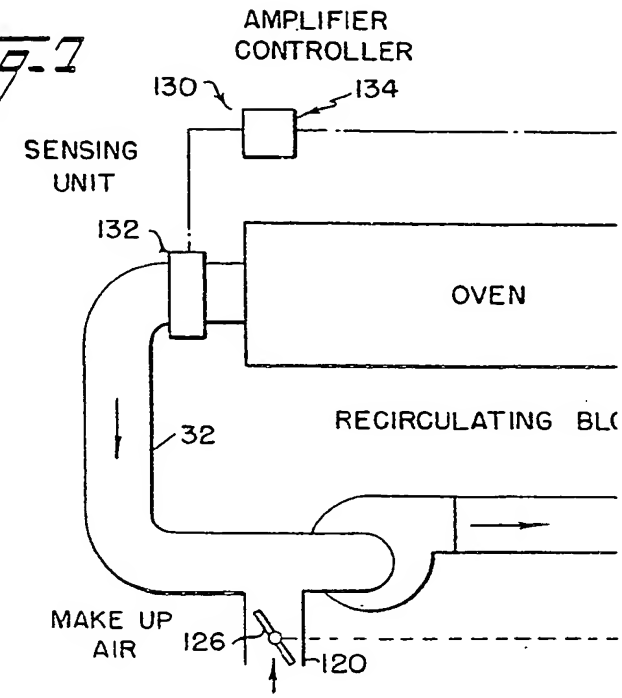
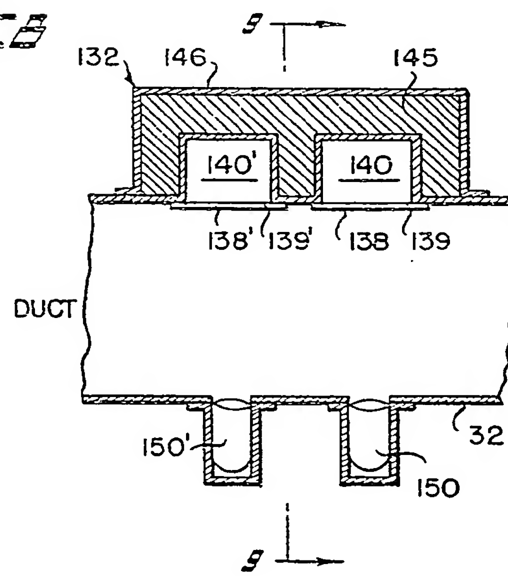
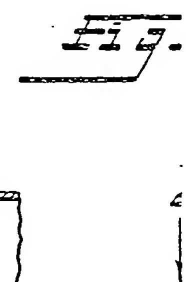

AMPLIFIER
CONTROLLER
130
134
SENSING
UNIT
132
OVEN
RECIRCULATING BL
32
MAKE UP
AIR
126
120

Fig. 8


9
132
146
145
140'
140
138'
139'
138
139
DUCT
32
150'
150
9



1046087 COMPLETE SPECIFICATION

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Sheet 4

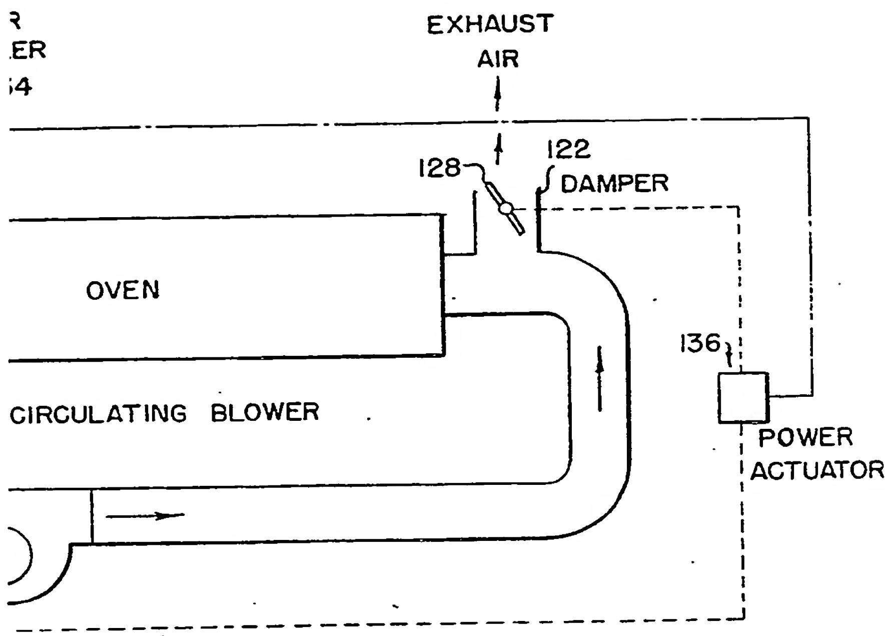

Fig. 9

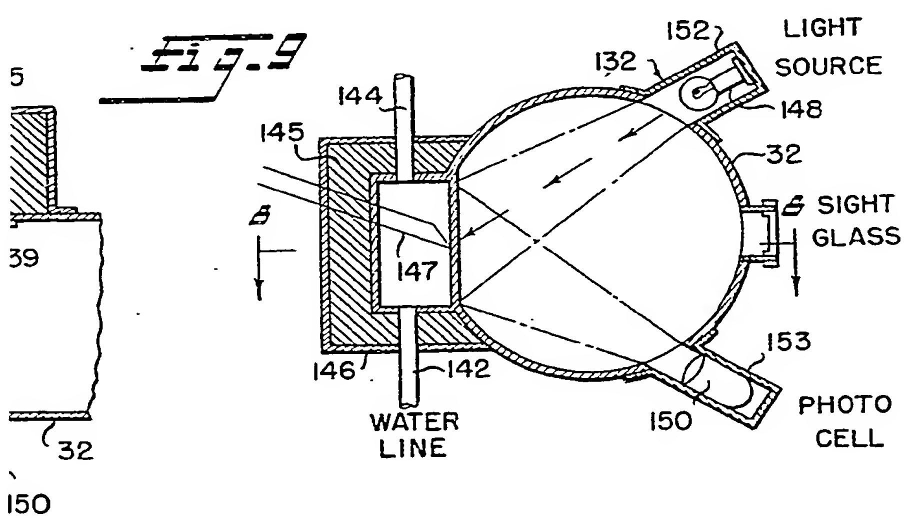

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Fig. 7.

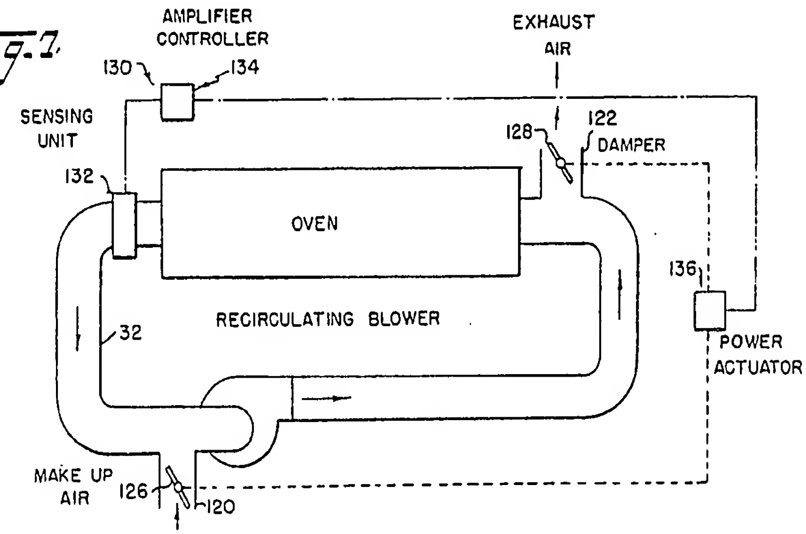

Fig. 8

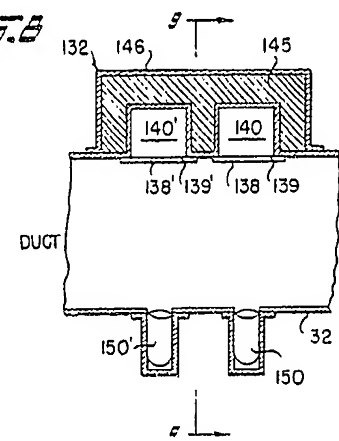

Fig. 9